Fermi National Accelerator Laboratory

W/Z + Jets Production at the Tevatron $\overline{\text{P}}$P Collider

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June 1995

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W/Z + JETS PRODUCTION AT THE TEVATRON $\overline{P}P$ COLLIDER [1]

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Abstract

Both the DØ and CDF experiments at Fermilab Tevatron collider at $\sqrt{s} = 1.8\text{TeV}$ have accumulated over $13pb^{-1}$ of data during the 1992-1993 collider run. Each experiment collected more than 10,000 $W \rightarrow l + \nu$ and 1,000 $Z \rightarrow l + \bar{l}$ candidates for each lepton species (e and μ). Using this large data sample of W and Z candidates, the two experiments are actively testing perturbative QCD predictions. Among the studies that are in progress, preliminary results of Z+jets characteristics, multiplicity distributions of associated jets, and a determination of the strong coupling constant using the ratio of the W+1jet to W + 0jet cross sections are presented.

Introduction

Perturbative Quantum Chromodynamics (pQCD) has been successful in describing experimental data involving jets in the final states. However, testing QCD predictions using the jet final states suffers from inherent experimental and theoretical uncertainties. This is due to the uncertainties involved in defining jets consistently in experiment and in theory, despite the local parton-hadron duality theorem [1]. The jet final states also involve wide range of momentum transfer scale (Q^2) which makes the theoretical predictions unreliable in some ranges of Q^2.

The final states with W or Z bosons have many advantages in testing QCD predictions. Experimentally, these events are easy to identify with relatively small background contamination. Theoretically, the predictions can be carried out with relatively less uncertainties due to the high momentum transfer scale ($Q^2 \sim M_W^2$ or M_Z^2) of the processes. These processes are also very important to understand the background to the top productions, such as $t\bar{t} \rightarrow l+jets$ channel.

In addition, the production cross sections of the W and Z bosons are relatively larger in the Tevatron energy ($\sqrt{s}$ =1.8 TeV) compared to any other accelerators. More than 10,000 $W \rightarrow l + \nu$ and 1,000 $Z \rightarrow l + \bar{l}$ events for each lepton species (e or μ) were accumulated during the 1992 - 93 Tevatron collider run and a factor 10 increase in statistics is expected at the end of the current run. The resulting large samples of W and Z boson events will provide a very good opportunity for testing QCD predictions.

Some preliminary results on the kinematic characteristics of jets associated with Z bosons are presented. Raw jet multiplicity distributions in association with W and Z bosons are presented followed by a determination of the strong coupling constant α_s using the ratio of the cross sections of the $W + 1$jet to $W + 0$ jet processes.

Z+jets characteristics

The leading jet E_T spectrum of the final state jets generally falls as $E_T^{-5 \sim -6}$ due to the massless nature of the partons in the final state. In contrast, the spectrum in $Z + N$jets events falls less steeply ($E_T^{-1.5 \sim -2}$). Figure 1.a shows the comparison of the spectrum to leading order (LO) prediction [2] incorporated with the CDF detector simulation [3]. The theoretical predictions are normalized to the data so that the shapes can be compared easily. The shape of the observed E_T spectrum is well described by the theoretical prediction within the given statistics.

The angular distribution of jets in the center of mass system depends on the spin of the mediator. The di-jet final state at the Tevatron energy is dominated by a gluon exchange. The gluons have spin 1 so that the the angular distribution of the jet follows the Ruthorford
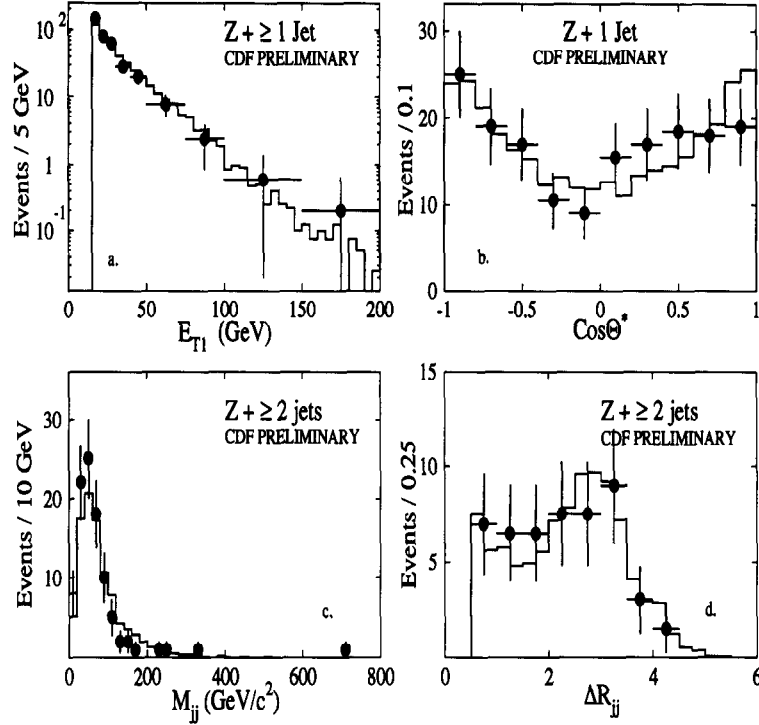
Figure 1: Some kinematic characteristics of jets in association with Z bosons from the CDF experiment. 1.a : Leading jet E_T spectrum, 1.b : Leading jet center of mass angular distributions, 1.c : Two jet invariant mass of the $Z+ \geq 2$ jet final states, and 1.d : Spatial distance between the two jets in $Z+ \geq 2$ jet events. Solid circles represent the data and the histograms illustrate LO predictions

scattering pattern: $1/(1 - cos\theta^*)^2$, where θ^* is the polar angle of the leading jet in the center of mass system. However, the W/Z+jets final state is dominated by spin 1/2 quark exchange. Therefore the angular distribution is expected to follow $1/(1 - cos\theta^*)$. Figure 1.b shows the angular distribution of the leading jet in the $Z+ \geq 2$ jet events along with the LO QCD predictions. One can observe that within the given statistics the angular distribution is well described by the LO theoretical prediction.

Figure 1.c shows the invariant mass distributions of the two jets in the $Z+ \geq 2$ jet final states. This quantity is interesting because any deviation from the Standard Model expectation of the $Z+ \geq 2$jet final state would show up as an enhanced resonance in this distribution. A good description of the data is given by the LO theoretical prediction.

Figure 1.d shows the distance in $\eta - \phi$ space between the two jets in $Z+ \geq 2$jet final states in comparison with the LO predictions. Again, good agreement within the given statistics can be observed.

W/Z+jet multiplicity distributions

The jet multiplicity distribution associated with the W or Z bosons have never been

a. (plot, top)

Fraction of Events vs Jet Multiplicity

CDF PRELIMINARY
● Z events, electrons
□ Z events, muons

b. (plot, bottom)

Fraction of Events vs Jet Multiplicity

CDF PRELIMINARY
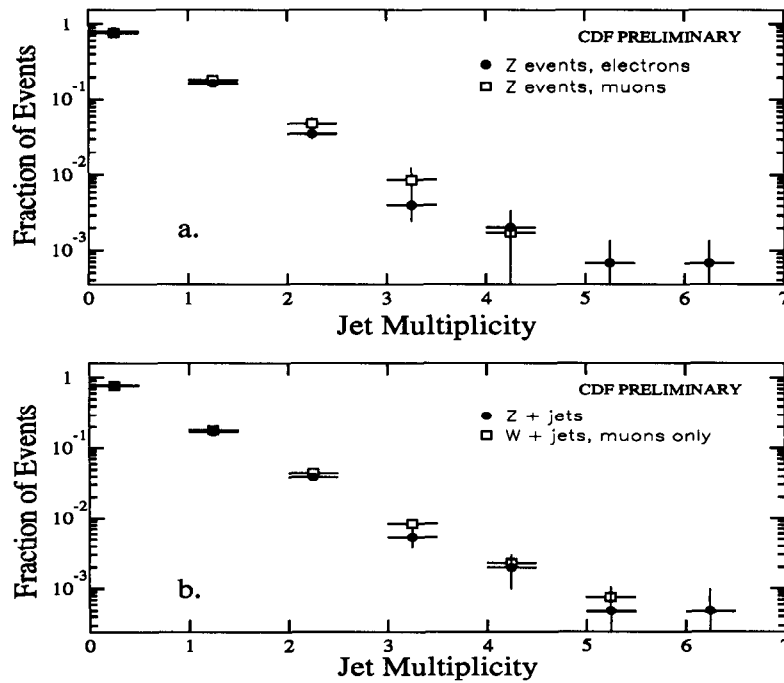● Z + jets
□ W + jets, muons only

Figure 2: Jet multiplicity distributions for W and Z bosons for leptonic decay channels. Figure 2.a: Z+jets multiplicity distributions for two leptonic decay modes of the Z, electrons in solid circles and muons in open squares. Figure 2.b: Jet multiplicity distributions for W and Z bosons decaying to muons final states. Solid circles represent multiplicity distribution for Z and the open squares illistrate that for W bosons.

measured in any other experiment. An accurate measurement of these cross sections is needed because only tree level calculations exist for the processes with jet multiplicity greater than one. Therefore, the uncertainty in the normalization of the predictions increases as the number of jet increases. With the large $W/Z + N$jets samples, it is possible to accurately measure the cross sections and to provide a proper normalization to the theory.

Since the probability of radiating an extra parton depends on the strong coupling constant α_s, the jet multiplicity distributions are expected to be proportional to $\mathcal{O}(\alpha_s^{Njets})$. Thus, one expects to observe a power law behavior in the multiplicity distributions. Figure 2.a shows the jet multiplicity distributions associated with the Z bosons decaying both into two electrons (solid circles) and two muons (open squares). The two distributions are normalized to the total number of events in each decay mode so that the shapes can be easily compared. The two distribution agrees very well with each other. This proves that the production mechanism of the vector bosons are independent of their decay modes as one expects.

Since the masses of W and Z bosons are not much different, one would expect to see the production mechanism do not differ greatly from each other. This is demonstrated in Fig. 2.b which shows the normalized jet multiplicity distributions for W and Z bosons for their muon decay channels. The shapes of the two distributions are indistinguishable.
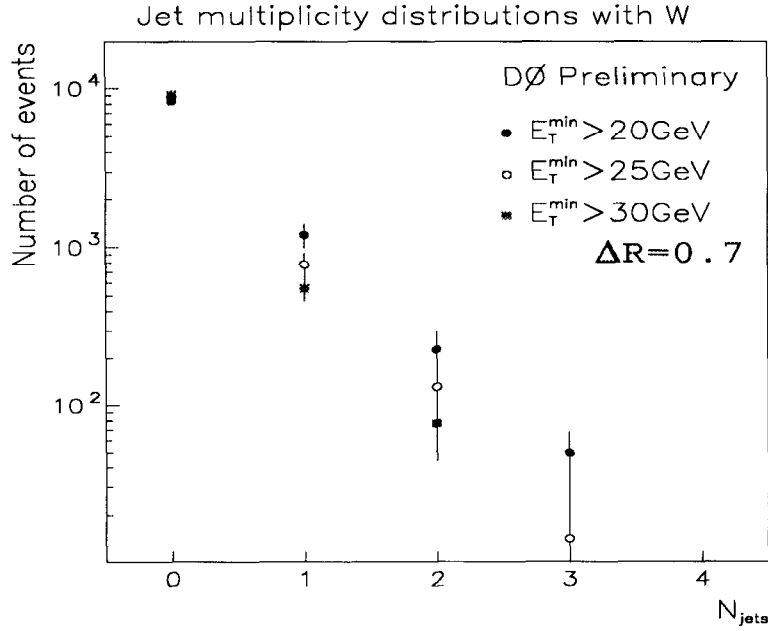
Figure 3: Jet multiplicity distributions for $W \to e\nu$ decay channel for various E_T^{min} cuts for jets.

Figure 3 shows the jet multiplicity distributions associated with $W \to e + \nu$ candidates from the DØ experiment. Different symbols represent various jet definitions with different jet E_T thresholds (E_T^{min}). The jet algorithm is a fixed cone algorithm with the radius of cone $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.7$. One can clearly observe that the power law behavior of the multiplicity distributions for all E_T^{min} values. One can also see that the distributions get steeper as the E_T^{min} increases from 20 GeV to 30 GeV. The probability of a radiated parton satistifying the jet definition decreases with increasing E_T^{min}.

α_s determination

In tree level calculations, one can find that the cross section of the $W + 1$ jet process is proportional to α_s whereas the cross section of the $W + 0$ jet process is independent of α_s. Therefore, the ratio of the $W + 1$jet to $W + 0$ jet cross section is proportional to α_s [4]. The DØ experiment uses this property of the ratio to determine the value of α_s at the mass of W, using next-to-leading order (NLO) predictions [5]. The cross sections are parameterized as $\sigma(W + njet) = \alpha_s^{njet}(a_n + \alpha_s b_n)$. The ratio can then be expressed as $\mathcal{R}_{pred} = \alpha_s(a_1 + \alpha_s b_1)/(a_0 + \alpha_s b_0)$. By equating this expression with the experimentally measured ratio $\mathcal{R}_{exp}$ and by solving the equation for α_s, a value of α_s can be obtained.

The DØ experiment finds the ratio, using 9770 $W \to e + \nu$ candidates, $\mathcal{R}_{exp} = 0.065 \pm 0.003(stat.) \pm 0.007(syst.)$ for $\Delta R = 0.7$ and $E_T^{min} = 25$ GeV. Using this measured ratio and the method described above, the DØ experiment determined the value of α_s for CTEQ1M pdf to be: 0.123 ± 0.015 [6]. The uncertainty is dominated by the experimental systematics due

to the jet energy scale.

One should note here that this value of α_s cannot be put on the same footing as those from LEP experiments, because this method of α_s determination fixes the α_s in the parton density functions (pdf) and varys α_s only in the hard scattering matrix elements (ME). However, the pdf's have implicit dependence on the value of α_s through the evolution of the pdf's determined at the lower energy scale (Q_0^2) to the scale of interest ($Q^2 = M_W^2$ in this case). A complete way of α_s determination requires varying α_s simultaneously in the pdf and ME. In order to achieve this goal, one needs to vary α_s (or Λ_{QCD}) in the pdf's and re-fit all the other parameters in the pdf accordingly. This study will be possible in the very near future with the help from various pdf groups (MRS, GRV, and CTEQ) [7].

Conclusions

Using the large samples of W and Z bosons, the DØ and CDF experiments at Fermilab are intensively testing QCD predictions. Various kinematic quantities of the jets associated with the bosons show good agreement between data and theoretical predictions. The jet multiplicity distributions are measured and show the expected scaling behavior as a funciton of the multiplicity. The strong coupling constant has been determined using the ratio of the $W + 1$ jet and $W + 0$ jet cross sections for CTEQ1M parton distributions. Although this value of α_s determined in this way can not have the same meaning as those from the LEP measurements, the measured value of α_s provides a good consistency check of the pdf's. A more comprehensive study of α_s determination will be done in the near future.

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